



2015 Minerals Yearbook

THORIUM [ADVANCE RELEASE]

THORIUM

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There was no reported domestic production, imports, or exports of thorium ores and concentrates in 2015. Thorium alloys, compounds, and metal used by the domestic industry were derived from imports or stocks. In 2015, India was the source of 95% of thorium compound imports to the United States. Imports decreased by 75% compared with an anomalous peak in 2014. In 2015, the United States was a net importer of thorium compounds, and the value of thorium compounds imported by the domestic industry was \$776,000. Domestic producers of thorium compounds processed imports into higher unit value exports. In 2015, the unit value of domestic exports of thorium compounds was \$359 per kilogram compared with \$78 per kilogram for U.S. imports for consumption according to data collected by the U.S. Census Bureau (tables 1, 2). Global mine production of monazite concentrate was 6,860 metric tons (t) (table 3).

Thorium occurs widely but is concentrated in only a few geologic deposit types. Three principal sources of thorium are of commercial interest—monazite in heavy-mineral-sand placer and vein deposits, thorite ores in vein deposits, and thorium recovered as a byproduct of uranium mining. Thorium and its compounds were produced primarily from the mineral monazite, which was recovered as a byproduct of processing placer sands for zircon and titanium minerals (ilmenite and rutile), or for the tin mineral cassiterite. Monazite was recovered primarily for its rare-earth-element (REE) content and only a small fraction of the byproduct thorium produced was consumed. In 2015, monazite-producing countries included Brazil, India, Malaysia, Thailand, and Vietnam. Other countries such as China produced monazite and thorium compounds, but data were inadequate for the formulation of reliable production estimates (table 3).

Issues associated with thorium's natural radioactivity were a significant deterrent to its commercial use. Excess thorium that was not designated for commercial use was either disposed of as a low-level radioactive waste or stored. Although research into thorium-fueled nuclear reactors continues, there were no industrial-scale nuclear reactors using thorium in 2015.

In the United States, only minor amounts, estimated at about 1 t of thorium oxide (ThO₂), are typically used annually. Principal uses include ceramics, catalysts, lighting, and welding electrodes. Large fluctuations in apparent consumption are caused by intermittent use, especially for applications that do not require annual replenishment of thorium supply.

Production

Domestic mine production data for thorium-bearing minerals were developed by the U.S. Geological Survey from a voluntary canvass of U.S. mining operations and information

gathered from publically available reports. Although monazite itself may be recovered as a byproduct of processing heavy-mineral sands, monazite was not produced domestically as a salable product in 2015.

Consumption

Thorium consumption worldwide is small compared with that of most other mineral commodities. Thorium is used in a variety of catalysts, ceramics, optics, and metal applications. In catalysts, ThO₂ is used in petroleum fluid catalytic cracking (converting crude oil into lighter fractions) and in the production of nitric and sulfuric acids. One of the major uses of thorium is in the form of thoriated tungsten metal. Thorium lowers the energy necessary for electrons to escape from a tungsten surface and enhances the thermionic emission. In welding and plasma cutting, thoriated tungsten electrodes improve ignition and arc stability. Thoriated tungsten filaments are used in high-intensity discharge lamps, vacuum tubes for radio transmitters and audio amplifiers, and cathode heaters. As a fluoride, thorium is used within antireflection materials in optical coatings. One of the oldest uses of thorium is in the manufacture of incandescent gas mantles. Gas mantles containing ThO₂ provide an intense white light but were not produced domestically owing to the availability of suitable substitutes. In the past, thorium has been used as an alloying agent in magnesium and nickel alloys for heat-resistant applications. Because of concerns about its naturally occurring radioactivity, thorium has been replaced by nonradioactive materials in many uses. Interest in thorium as a nuclear fuel continues in part owing to its high abundance relative to uranium.

Statistics on domestic thorium consumption were developed by evaluating import and export data and canvassing processors. Insufficient data were collected from thorium processors to determine consumption of ThO₂ equivalent in 2015. Thorium alloys and compounds used by the domestic industry were derived from imports or stockpiled inventory.

Several companies and countries were active in the pursuit of commercializing thorium as a nuclear fuel material. Thorium-based nuclear research and development programs have been underway in Belgium, Brazil, Canada, China, the Czech Republic, France, Germany, India, Israel, Japan, the Netherlands, Norway, Russia, the United Kingdom, and the United States.

In the United States, companies known to be involved in these efforts included Babcock & Wilcox Nuclear Energy, Inc. (Charlotte, NC), Flibe Energy Inc. (Huntsville, AL), General Atomics (San Diego, CA), Lightbridge Corp. (Reston, VA), Martingale Inc. (Tavernier, FL), TerraPower, LLC

¹Deceased.

(Bellevue, WA), Transatomic Power Corp. (Cambridge, MA), and X-energy, LLC (Greenbelt, MD).

Prices

Published prices for ThO₂ and nitrate were not available. According to export statistics from India's Ministry of Commerce, the unit value of thorium nitrate exports was \$53 per kilogram, an 8% decrease compared with the unit value in 2014 (Global Trade Information Services Inc., 2016). In the United States, the average unit value of imported thorium compounds was \$78 per kilogram, a 13% increase compared with \$69 per kilogram in 2014. The average unit value of exported thorium compounds increased to \$359 per kilogram from \$129 per kilogram in 2014 (table 2). For imports and exports, the data are often skewed by a mix of high-volume, low-unit-value imports and low-volume, high-unit-value imports.

Foreign Trade

Owing to limited demand, thorium ores and concentrates and thorium compounds are imported and exported sporadically. There were no reported imports or exports of thorium ores and concentrates in 2015. Imports of thorium ores were last reported in 2012. Exports of thorium compounds from the United States were 2.16 t valued at \$776,000, a decrease from 15.25 t valued at \$1,970,000 in 2014 (table 2). The principal destination was the United Kingdom (72%). Imports of thorium compounds in 2015 totaled 2.74 t valued at \$214,000, a decrease from 11.01 t valued at \$761,000 in 2014. India continued to be the leading supplier of thorium compound imports in 2015.

World Review

Thorium demand worldwide was limited by concerns about its naturally occurring radioactivity. In 2015, exploration and development of several rare-earth projects associated with thorium were underway, but progress on most projects slowed because of an oversupply of rare-earth materials and declining prices.

Brazil.—After an unexplained hiatus in 2014, Brazil exported an estimated 1,600 t of monazite concentrate to China in 2015 (Global Trade Information Services Inc., 2016). Although no data were available for 2015, according to the Departamento Nacional de Produção Mineral (DNPM), Brazil's prior shipments were derived from Indústrias Nucleares do Brasil S.A. (INB) inventories in Sao Francisco do Itabapoana (Andrade, 2016, p. 108, 109). INB reported that it produced monazite concentrate from previously mined ore and heavy mineral concentrates at its Buena operations in Sao Francisco de Itabapoana, Rio de Janeiro State (Indústrias Nucleares do Brasil S.A., undated).

Canada.—Medallion Resources Ltd. continued to pursue plans to develop a processing facility for the production of mixed rare-earth compounds from monazite. Medallion's proposed facility would purchase monazite byproduct from heavy-mineral-sands operations and produce rare-earth compounds. In 2015, the company was conducting lab-scale metallurgical testing, refining plans for a pilot-plant facility,

and testing samples from heavy-mineral sands producers, to locate suitable monazite feed. The company also reported it had produced lab-scale quantiles of mixed rare-earth chemical concentrates for evaluation by commercial consumers (Medallion Resources Ltd., 2016).

Based on a revised business plan, Pele Mountain Resources Inc. pursued the development of a monazite-processing operation at Elliot Lake, Ontario, that would source its feedstock from mineral sands mine tailings in other countries. In March, Pele agreed to a memorandum of understanding (MOU) with Sheng Kang Ning Mining Investment Co. Ltd. (SKN) to establish a joint-venture operation at Pele's Eco Ridge property in Elliot Lake; however, one of the pre-conditions of MOU was the receipt of Chinese Government approval for SKN to use its proprietary separation technology in Elliot Lake. In September, the understanding expired because SKN had yet to receive the necessary approvals. At yearend, Pele continued to pursue collaborative work with SKN and other interested parties (Pele Mountain Resources Inc., 2015a, b).

In January, Commerce Resources Corp. announced the completion of a revised preliminary economic assessment for the development of its Ashram project in northern Quebec. Measured and indicated resources were estimated to be 29.3 Mt containing 1.90% rare-earth oxide (REO), using a 1.25% REO cutoff grade. The proposed project was based on the production of 16,900 metric tons per year (t/yr) of REO equivalent derived from monazite and to a lesser degree bastnäsite and xenotime. In 2015, prefeasibility, drilling, and pilot plant studies were ongoing. Thorium was to be selectively removed and planned to report to the mill tailings (Commerce Resources Corp., 2015, p. 12–13, 135; 2016, p. 2–4).

China.—China produced substantial but unknown quantities of thorium byproducts during the processing of domestic and imported mineral concentrates for the production of rare-earth compounds. In 2015, China's imports of thorium ores and concentrates were 4,640 t (gross weight) and the leading import sources were Thailand (1,890 t), Brazil (1,230 t), Malaysia (609 t), and Laos (495 t). Thorium may also be present in mixed heavy-mineral concentrates not specifically classified as thorium bearing.

The Chinese Academy of Sciences continued an initiative to develop thorium molten-salt reactor (TMSR) technologies. In 2015, the effort employed a staff of about 700 scientists and engineers and was led by the TMSR Center at the Shanghai Institute of Applied Physics (SINAP). The TMSR Center planned for the construction of two 2-megawatt (MW) research reactors by 2017. Construction of a 1,000-MW reactor in the 2030s was expected to help demonstrate the commercial feasibility of the technology. In March, as part of an ongoing collaborative agreement, researchers from SINAP and Oak Ridge National Laboratory met at Oak Ridge, TN, to discuss the development of salt-cooled reactors (Martin, 2015; Oak Ridge National Laboratory, 2015).

Greenland.—Greenland Minerals and Energy Ltd. (GMEL) continued to advance its Kvanefjeld Project for production of fluorspar, rare-earth, uranium, and zinc concentrates and refined compounds. In 2015, GMEL announced it had filed an exploitation license and had completed a feasibility study, as

well as environmental and social impact assessments. GMEL's initial proven and probable reserve estimate completed in 2015 included 108 Mt of ore containing 362 parts per million (ppm) U_3O_8 , 2,600 ppm zinc, and 14,300 ppm REO. GMEL's feasibility study included a base-case scenario to process 3 Mt per year of ore with a 37-year mine life (Greenland Minerals and Energy Ltd., 2016). Unspecified quantities of thorium contained in the concentrates were expected to be removed along with other impurities during the processing of the mineral concentrates. Pilot plant studies to produce uranium- and thorium-free compounds from Kvanefjeld concentrates were funded in part by the European Commission to promote the development of a rare-earth industry in Europe (World Nuclear News, 2015).

India.—In 2015, India's producers of monazite concentrate included Indian Rare Earths Ltd. (IREL) and Kerala Metals & Minerals Ltd. (KMML). IREL's Aluva Rare Earth Division (RED) in the Ernakulam district, Kerala State, was capable of processing monazite into rare-earth compounds and thorium hydroxide. According to the Indian Bureau of Mines, IREL has built a large stockpile of impure thorium hydroxide associated with rare earths and unreacted materials (Indian Bureau of Mines, 2016). In Odisha State, IREL was commissioning a processing plant that would consume monazite and could produce up to 11,000 t/yr of mixed rare-earth chloride, 13,500 t/yr of tri-sodium phosphate, and 150 t/yr of thorium nitrate (Singh, 2016).

India's capacity to produce electrical power from nuclear reactors was less than 7 gigawatts (GW); however, several nuclear reactors were under construction and plans were in place to raise the nuclear electrical capacity to 63 GW by 2032 and more than 270 GW by 2050 through a three-stage development program. Although initially based on uranium, in the later stages of the program, India plans to make use of its significant resources of thorium. In 2015, India's Department of Atomic Energy continued the development of an advanced heavy water reactor (AHWR) fueled by a thorium-mixed-oxide fuel and its molten-salt reactor technology. At the Bhabha Atomic Research Centre, a 300-MW demonstration AHWR was expected to be operational by 2022 (World Nuclear Association, 2016).

Kazakhstan.—Summit Atom Rare Earth Co. (SARECO), a joint venture between Japan's Sumitomo Corp. and Kazakhstan's Kazatomprom National Atomic Co., idled its newly commissioned plant in Stepnogorsk designed to recover rare earths from uranium-ore residue. The SARECO plant's design capacity was 1,500 t/yr of REO equivalent. In August, operations were suspended and, by yearend, Sumitomo Corp. planned to sell its 49% share in the venture (Kazatomprom National Atomic Co., 2016, p. 70).

Norway.—The Thorium Irradiation Consortium began a second round of nuclear fuel testing at the Institute for Energy Technology in Halden. Data were being gathered on several variants of thorium-mixed-oxide fuels as potential supplement fuel in conventional nuclear reactors. Thor Energy AS led the Thorium Irradiation Consortium (TIC), a partnership with an international consortium of utilities, industry, and research organizations whose other members included Atomic Energy Research Institute (Republic of Korea), Fortum Oyj

(Finland), Institute for Energy Technology (Norway), Institute for Transuranium Elements (Germany), National Nuclear Laboratory (United Kingdom), and Westinghouse Electric Co. (United States) (Thor Energy AS, 2016).

South Africa.—Steenkampskraal Thorium Ltd (STL) acquired the Steenkampskraal Mine (SKK) in the Western Cape Province from the bankrupt Great Western Minerals Group Ltd. STL planned to continue the refurbishment the Steenkampskraal monazite mine for the production of rare-earth minerals and thorium compounds for the production of thorium-based fuel for nuclear reactors (Steenkampskraal Thorium Ltd., 2015). According to an NI 43-101-compliant study completed in 2013, using a 1% REO cutoff grade, SKK's in situ measured resource was 85,000 t and contained about 2.82% ThO_2 . Using the same cutoff basis, indicated resources were estimated at 154,000 t and contained about 2.09% ThO_2 (Great Western Minerals Group Ltd., 2014).

Outlook

During the next decade, concerns related to thorium's natural radioactivity are expected to continue to limit its use in nonenergy applications. At the same time, the potential supply from rare-earth production is expected to increase over time. In the long term, thorium's consumption will increase substantially if its use as a nuclear fuel becomes commercialized.

The U.S. Nuclear Regulatory Commission (NRC) has put forth possible scenarios for using thorium in the nuclear fuel cycle, including use in different nuclear reactor types, and predicted that the most likely near-term nuclear application of thorium in the United States was in existing operating light water reactors (LWRs). Thorium use in LWRs would mix thorium with uranium, add thorium fuel to LWR fuel assemblies, or use mixed plutonium and thorium fuel assemblies (U.S. Nuclear Regulatory Commission, 2014, p. iii).

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TABLE 1
SALIENT U.S. THORIUM STATISTICS¹

| | | 2011 | 2012 | 2013 | 2014 | 2015 |
|--|----------------------|------|------|------|-------|------|
| Exports, gross weight, thorium compounds | metric tons | 4.28 | 3.16 | 1.01 | 15.30 | 2.16 |
| Imports for consumption, gross weight: | | | | | | |
| Thorium ores and concentrates, including monazite | do. | 30 | 43 | -- | -- | -- |
| Thorium compounds | do. | 5.71 | 4.40 | 2.83 | 11.00 | 2.74 |
| Prices, yearend, thorium compounds, gross weight: ² | | | | | | |
| France | dollars per kilogram | 158 | 153 | NA | NA | NA |
| India | do. | 58 | 60 | 65 | 65 | 63 |

do. Ditto. NA Not available. -- Zero.

¹Data are rounded to no more than three significant digits; may not add to totals shown.

²Source: U.S. Census Bureau.

TABLE 2
U.S. FOREIGN TRADE IN THORIUM AND THORIUM-BEARING MATERIALS¹

| | 2014 | | 2015 | |
|--|---------------------------|-----------|---------------------------|---------|
| | Quantity (metric tons) | Value | Quantity (metric tons) | Value |
| Exports, thorium compounds (HTS ² code 2844.30.1000): | | | | |
| Colombia | 5.49 | \$13,900 | -- | -- |
| Korea, Republic of | 6.46 | 900,000 | (3) | \$4,000 |
| United Kingdom | 2.60 | 496,000 | 1.56 | 343,000 |
| Other | 0.71 | 559,000 | 0.61 | 429,000 |
| Total | 15.30 | 1,970,000 | 2.16 | 776,000 |
| Imports for consumption, thorium compounds (HTS ² code 2844.30.1000): | | | | |
| India | 11.00 | 715,000 | 2.59 | 163,000 |
| Other | 0.01 | 45,900 | 0.14 | 51,100 |
| Total | 11.00 | 761,000 | 2.74 | 214,000 |

-- Zero.

¹Data are rounded to no more than three significant digits; may not add to totals shown.

²Harmonized Tariff Schedule of the United States.

³Less than ½ unit.

Source: U.S. Census Bureau.

TABLE 3
MONAZITE CONCENTRATE: WORLD PRODUCTION, BY COUNTRY^{1,2}

(Metric tons, gross weight)

| Country ³ | 2011 | 2012 | 2013 | 2014 | 2015 |
|----------------------|--------------------|--------------------|--------------------|--------------------|-------|
| Brazil ⁴ | 290 | 2,700 ^r | 600 | -- | 1,600 |
| India ^{e,5} | 3,000 ^r | 3,000 ^r | 3,000 ^r | 3,000 ^r | 3,000 |
| Malaysia | 571 | 113 ^r | 261 ^r | 372 ^r | 499 |
| Thailand | 5,100 ^r | 200 ^r | 210 ^r | 3,200 ^r | 1,300 |
| Vietnam ⁶ | 360 ^r | 370 ^r | 180 ^r | -- ^r | 460 |
| World total | 9,320 ^r | 6,380 ^r | 4,250 ^r | 6,570 ^r | 6,860 |

^eEstimated. ^rRevised. -- Zero

¹World totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

²Includes data available through May 12, 2016.

³In addition to the countries listed, China, Indonesia, Nigeria, North Korea, the Republic of Korea, and countries of the Commonwealth of Independent States may have produced monazite, but available information was inadequate to make reliable estimates of output.

⁴Reported production was derived from stockpiled mineral concentrates.

⁵Production baseline for 2011–15 derived from heavy-mineral sands operations.

⁶Chinese imports from Vietnam. Rounded to two significant digits.